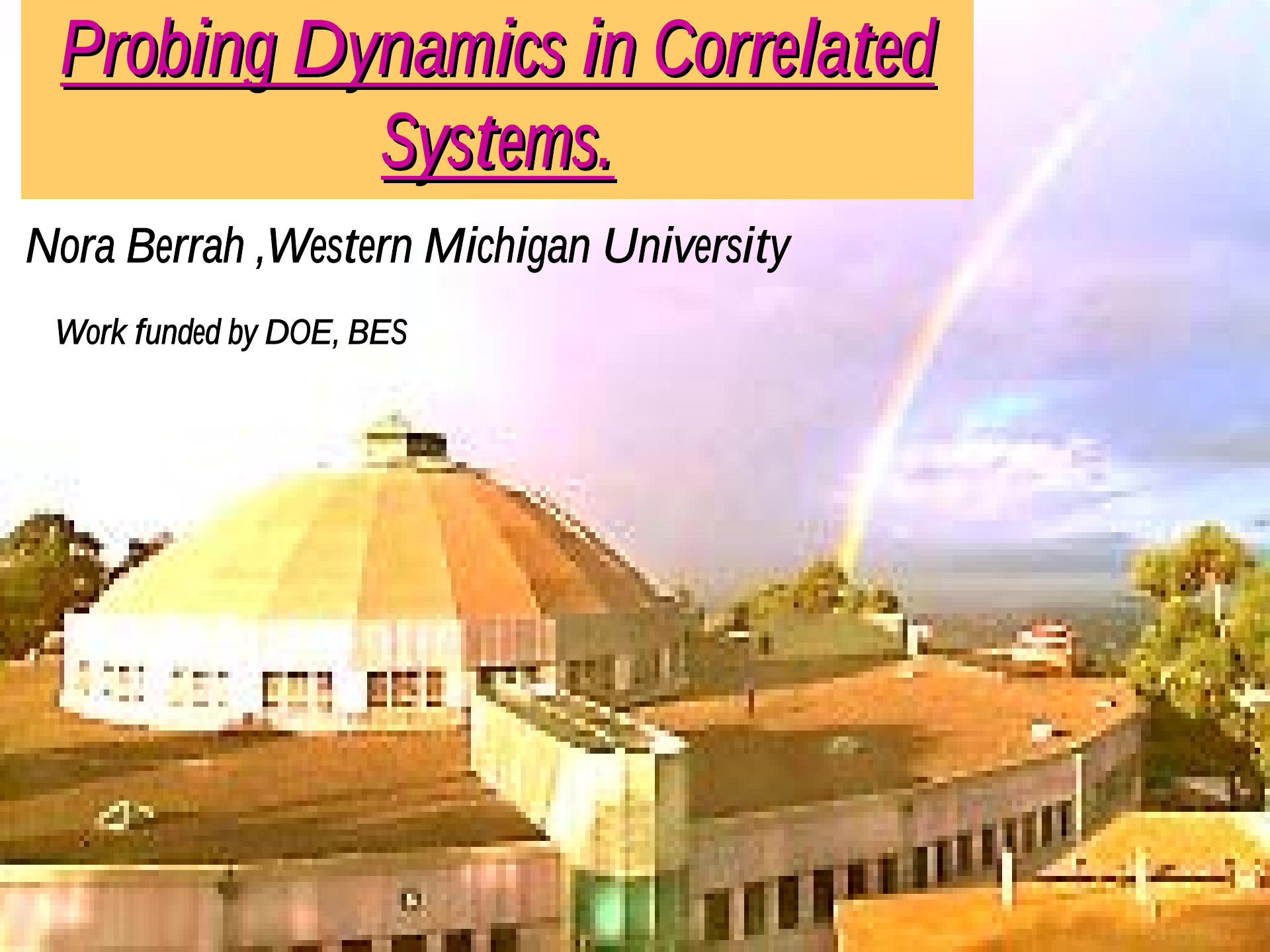
# Probing Dynamics in Correlated Systems.

*Nora Berrah ,Western Michigan University*

*Work funded by DOE, BES*



# What Could Lead to Exciting Science in Synch. Based AMO?

- **Time domaine science**; Time-resolved, Pump-probe, Ultrafast…..

*But also*

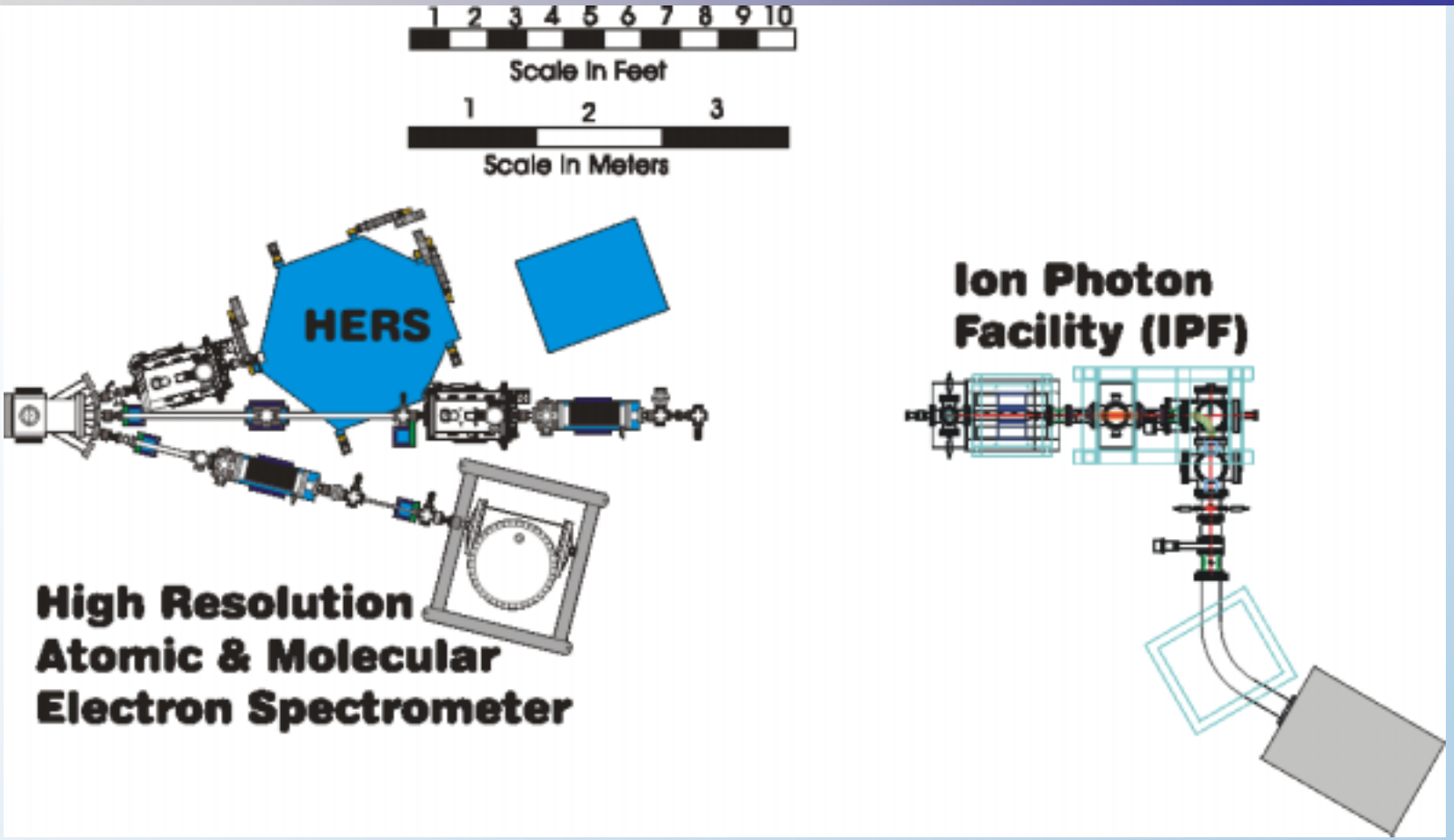
- **Samples** – opening a bottle of convenient atomic or diatomic gas is no longer sufficient

  *ions, clusters, excited states, radicals, jet cooling*

- **"Complete experiments"** – enough variability controlled or measured to unequivocally determine the underlying transition matrix elements and completely describe the photoinization event

  **i.e. CoITRIMS, electron spin measurements (for atoms)**

# BEAMLINE 10.0.1 – END STATIONS




- Beamline supports 3 permanent end-stations on three branches.
- Space available for independent investigators on central branch.
- Integrated differential pumping permitting high gas pressure in chamber.

# Why Study Ions ?

• 99.9% known universe exists in ionic state

• large theoretical effort (opacity project)  untested by experiment

•X ray opacities used to model high-T astrophysical & laboratory plasmas.

•Largely Unexplored Fundamental Science

Efforts at:

• SOLEIL (superACO), France

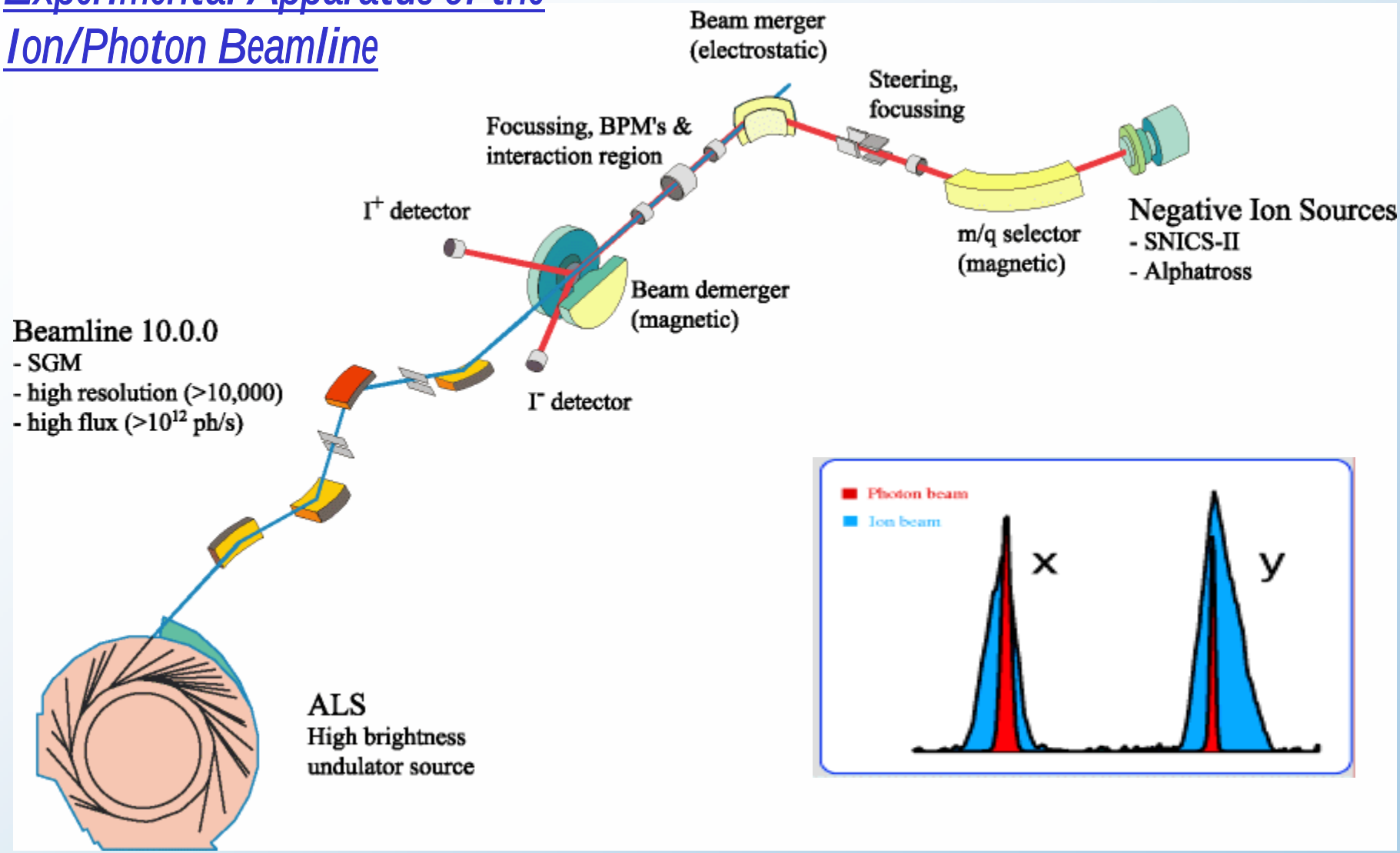
• ASTRID, Denmark

• ALS, USA

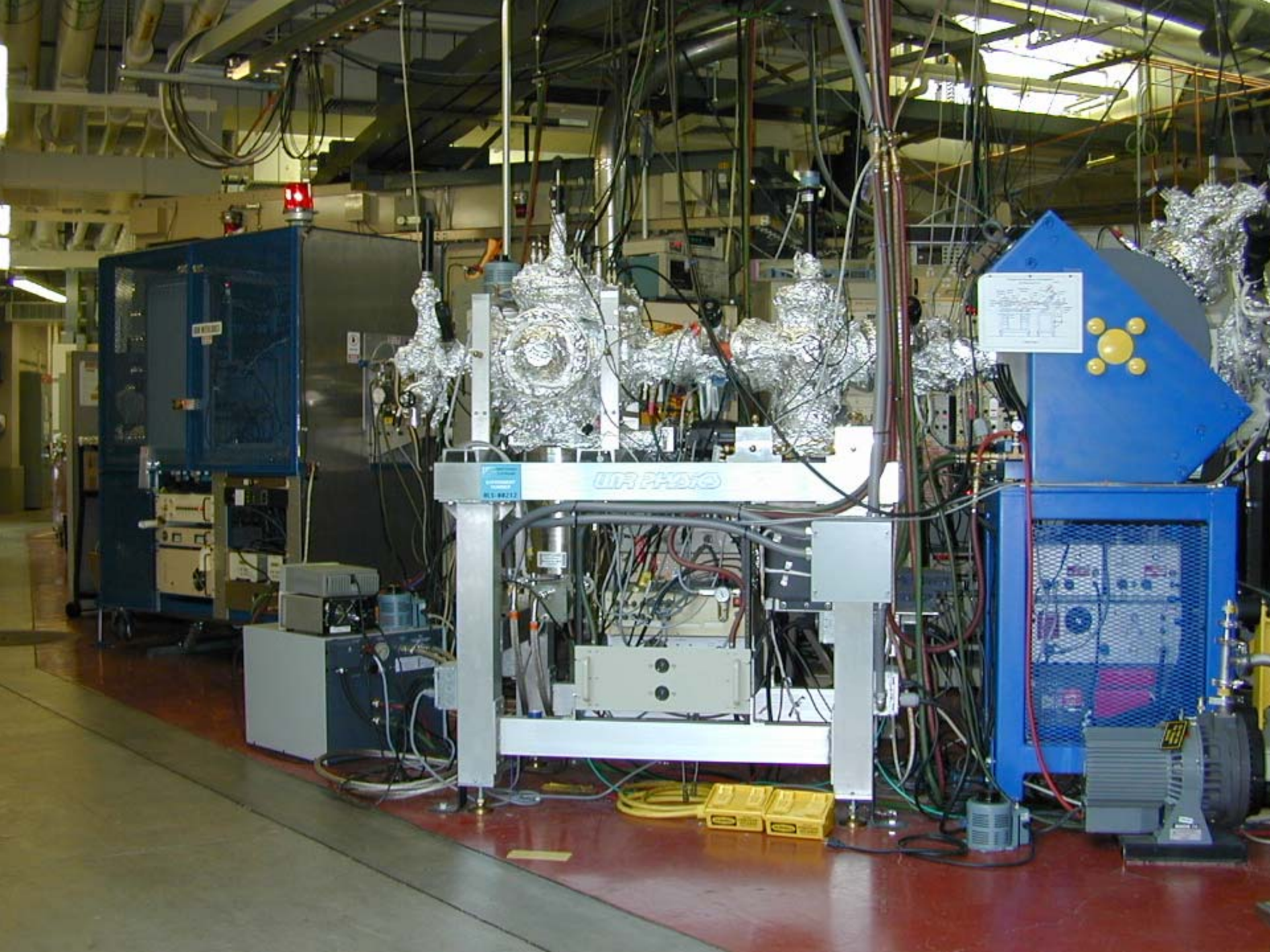
• Spring 8, Japan

• FEL, Hamburg, Germany

# Experimental Apparatus of the Ion/Photon Beamline



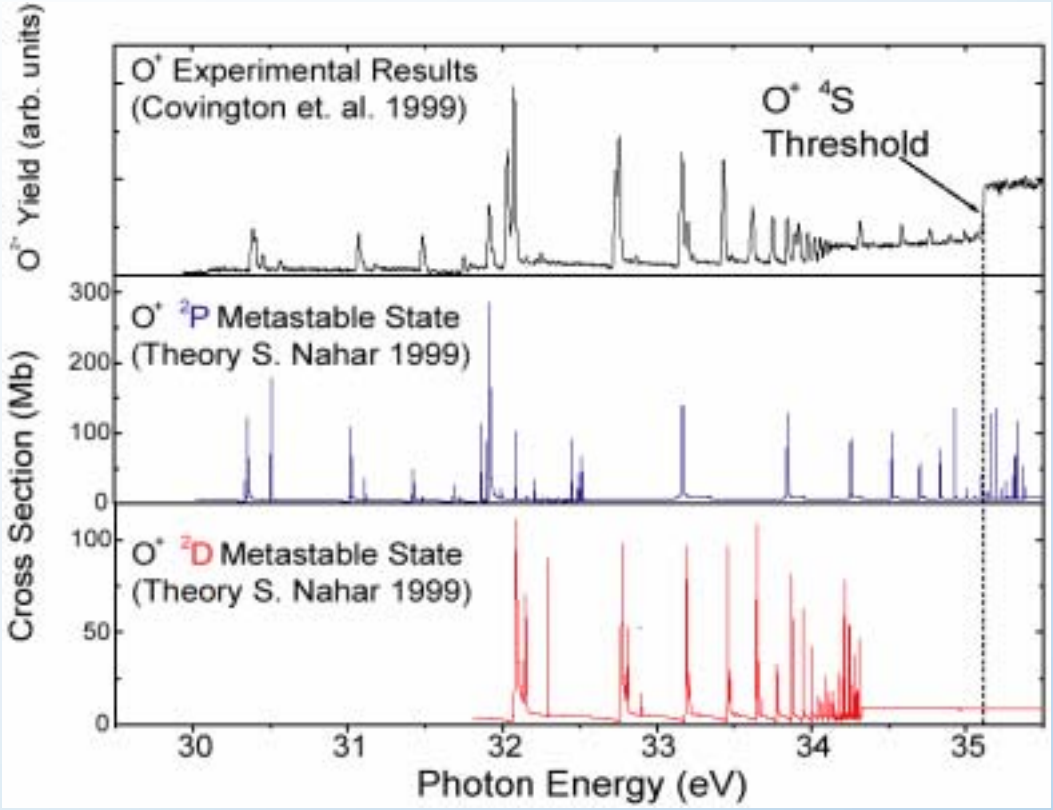

*Absolute cross sections of ions available from careful measurements of overlaps, photon & ion fluxes and detector efficiencies.*



# Photoionization of $O^+$

Several metastable states observed below ground state ionization threshold

Good correlation with R-matrix calculations by Nahar

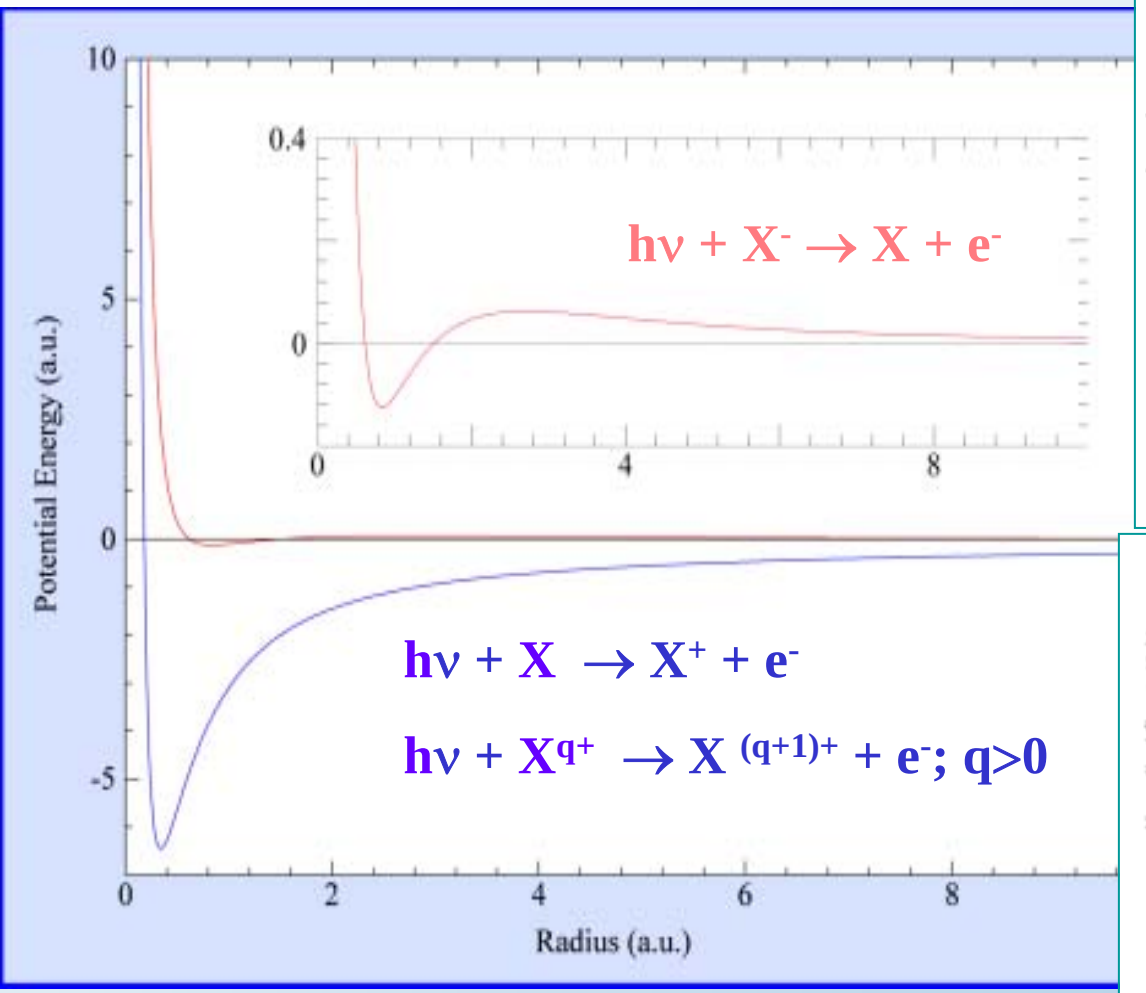


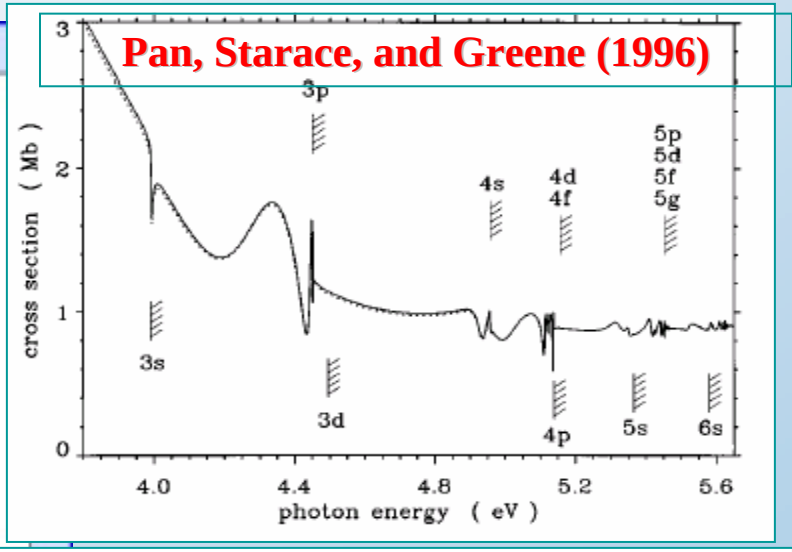

## Status:

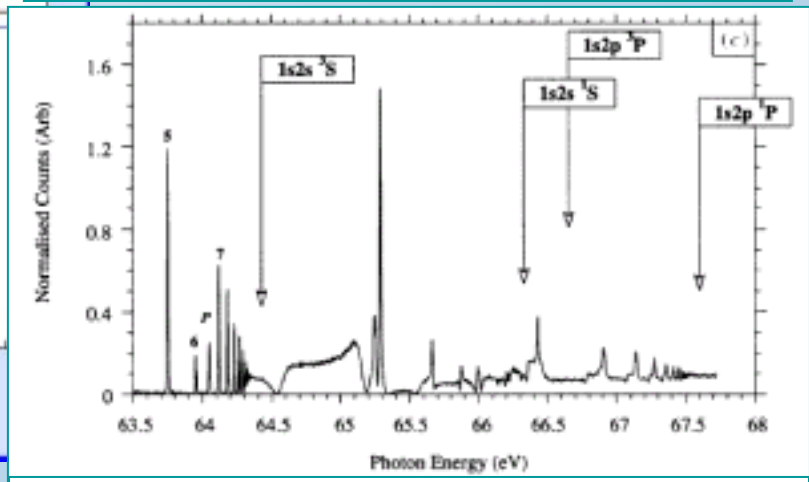
- Operations began 1999
- Singly charged species studied (using CIGA source): $O^+$, $Ar^+$, $Ne^+$, $Ca^+$
- Absolute photoionization cross sections obtained
- Multiply charged positive & negative ion sources installed in 2001/2002
- Strong collaboration with theory required for interpretation of results


R. Phaneuf, A. Covington, G. Hinojosa, A. Aguilar, I. Covington, C. Shirley (University of Nevada – Reno), J. Bozek, I. Dominguez, M. Sant'Ana, A. Schlachter (LBNL), I. Alvarez, C. Cisneros (UNA – Mexico), N. Berrah (U. Western Michigan) Phys. Rev, Lett, **87**, 243002 (2001).

# Comparison between Photoionization of Neutral Atoms/ Positive Ions and Photodetachment of Negative Ions




Kiernan et al. (1996)

# K-Shell Photodetachment of

## $He^-$ 1s2s2p $^4P^\circ$

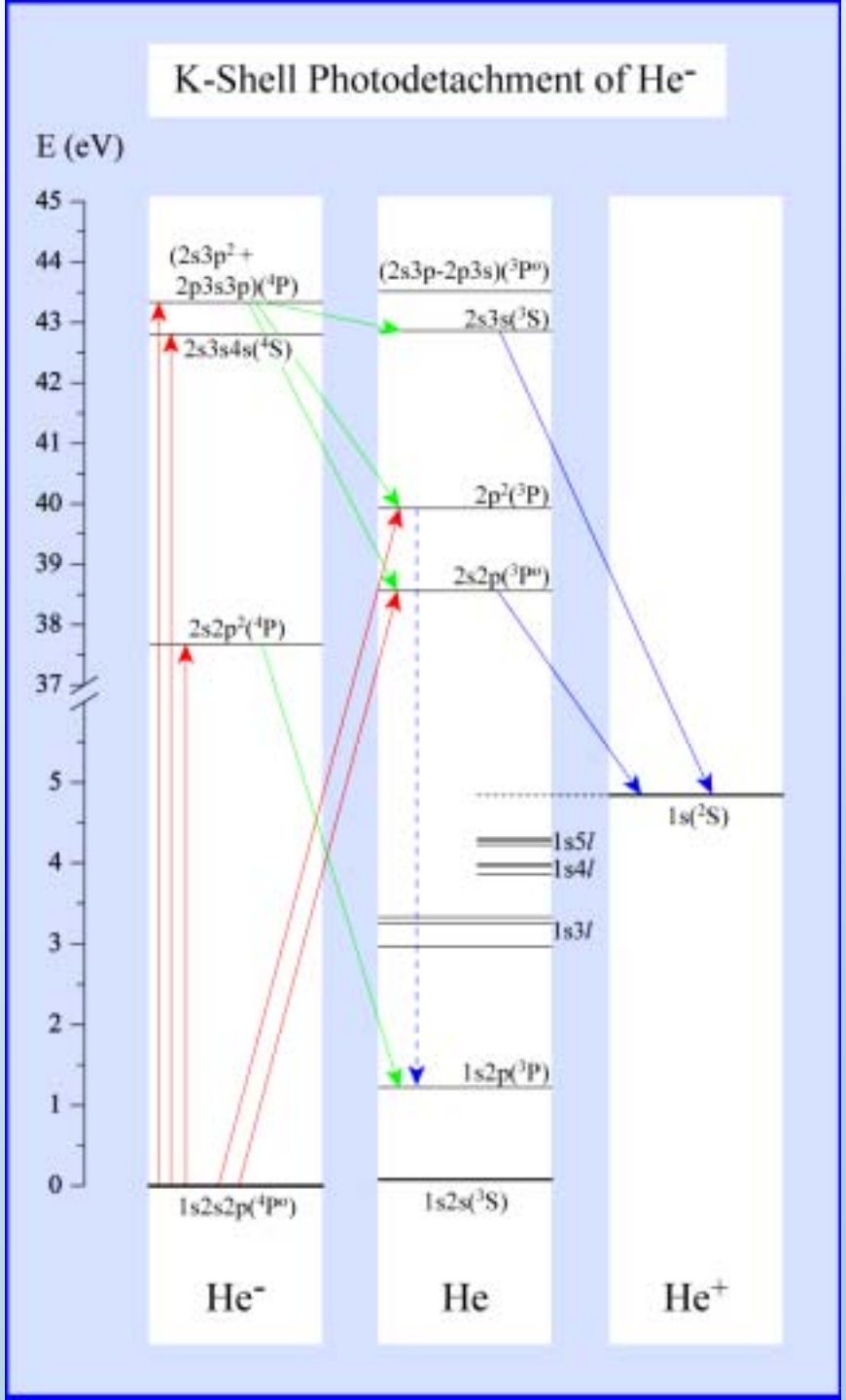
$h\nu + He^- \rightarrow He + e^-$

$\rightarrow He^* + e^-$

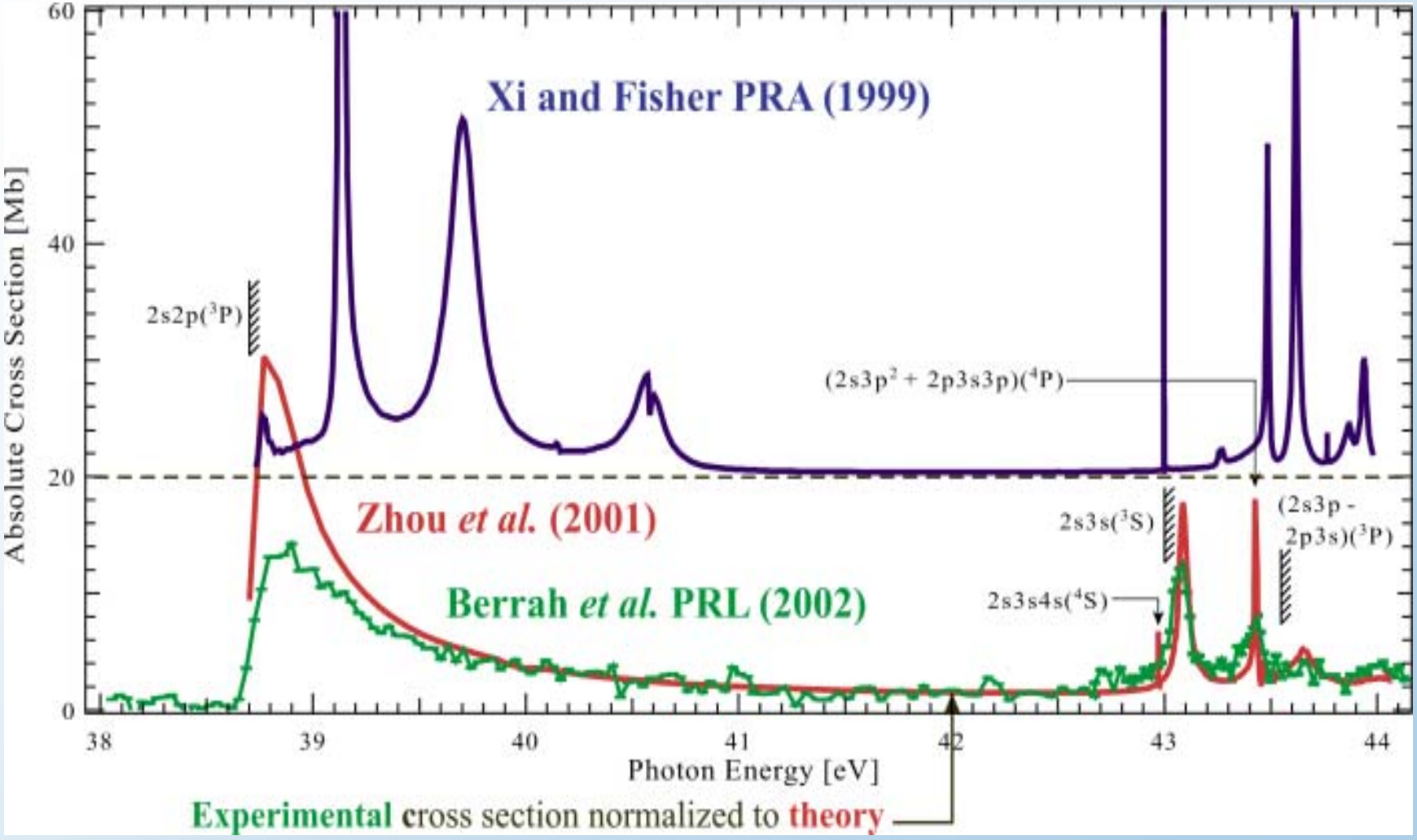
$\rightarrow He^+ + e^-_A + e^-$

**Probing Doubly and Triply Excited States!!**

**Hollow Ion/Atom**

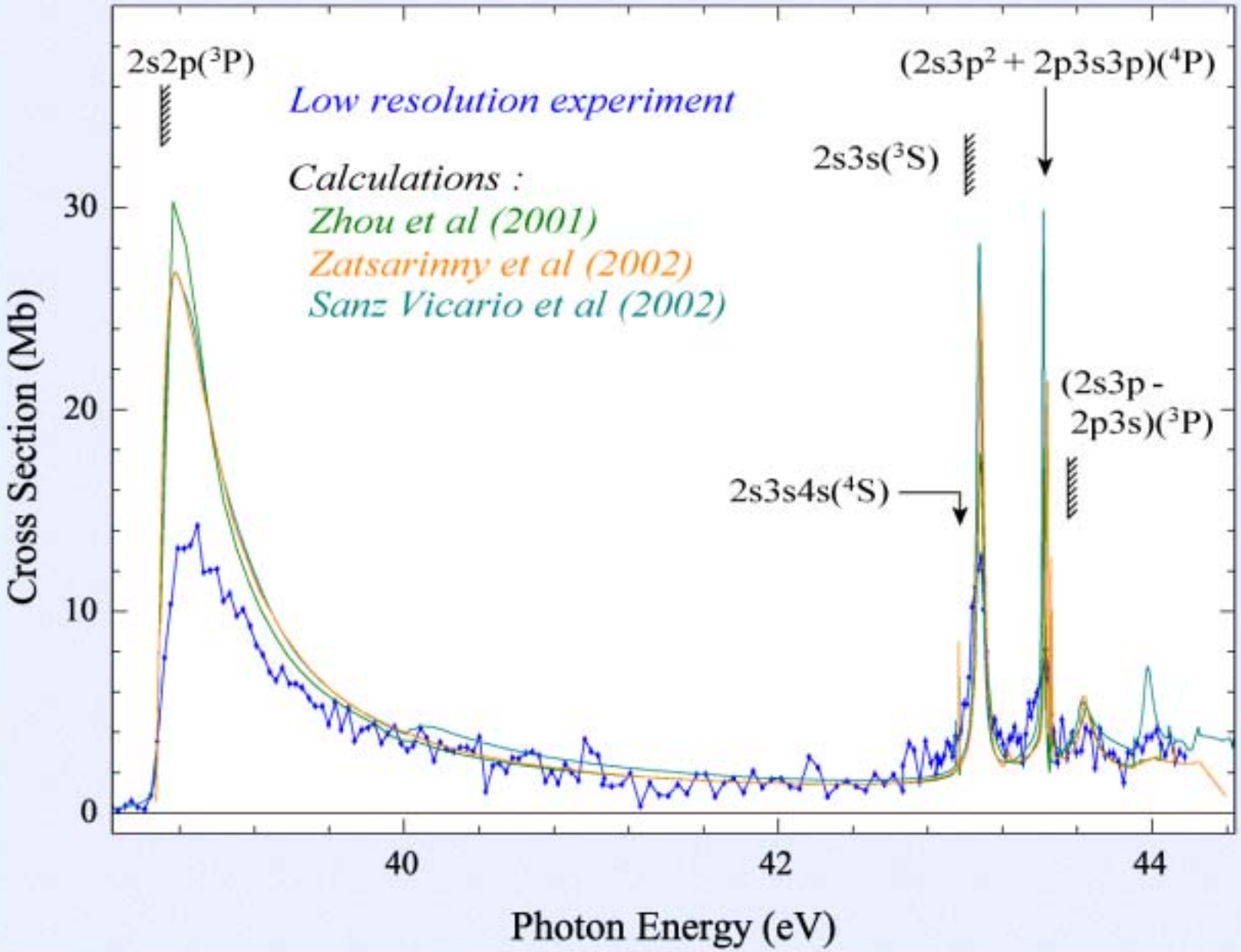


# K-Shell Photodetachment of $He^-$ :Comparison Between Two Calculations in Dispute



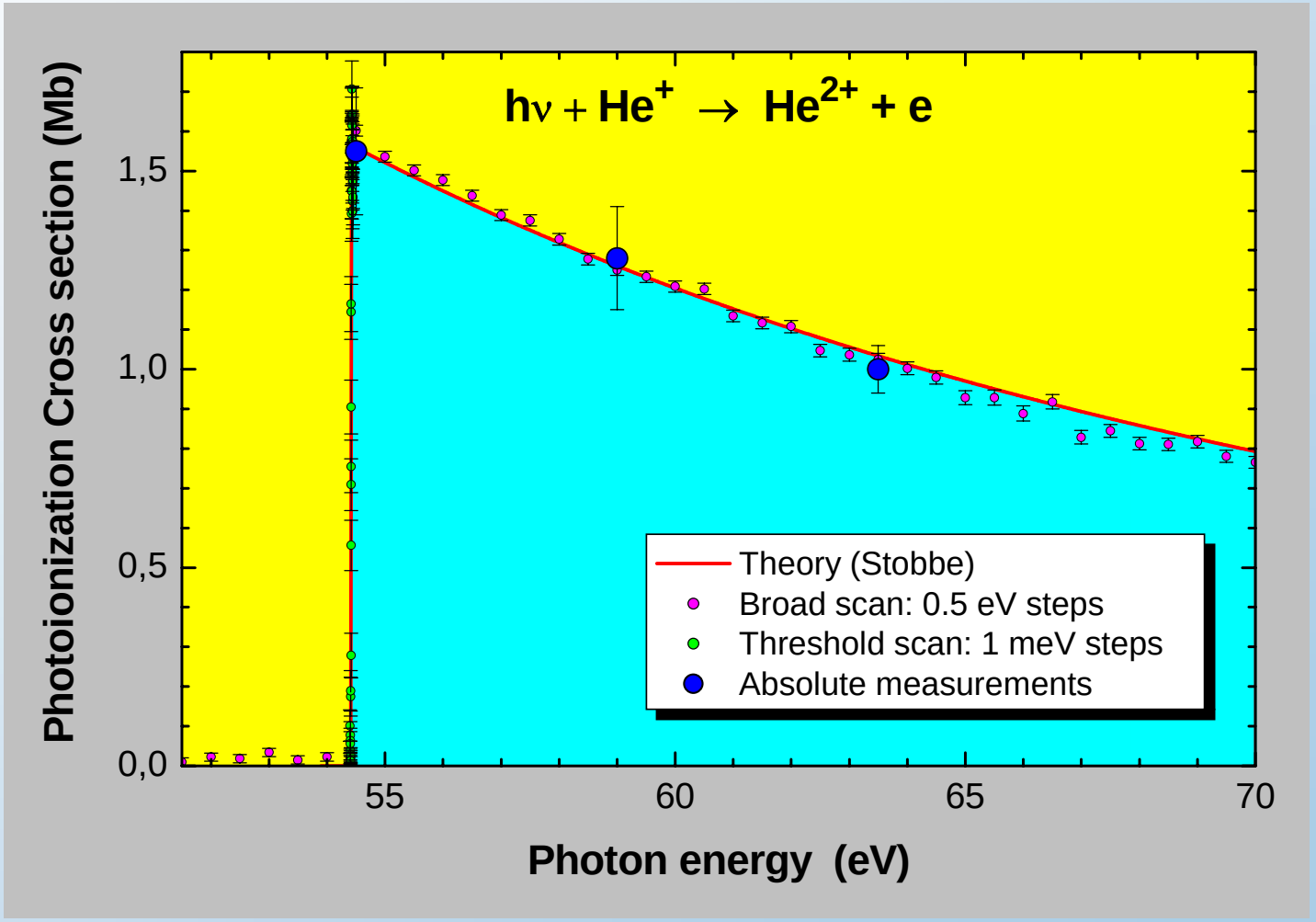

Berrah et al.Phys. Rev. Lett. **88**, 093001 (2002).

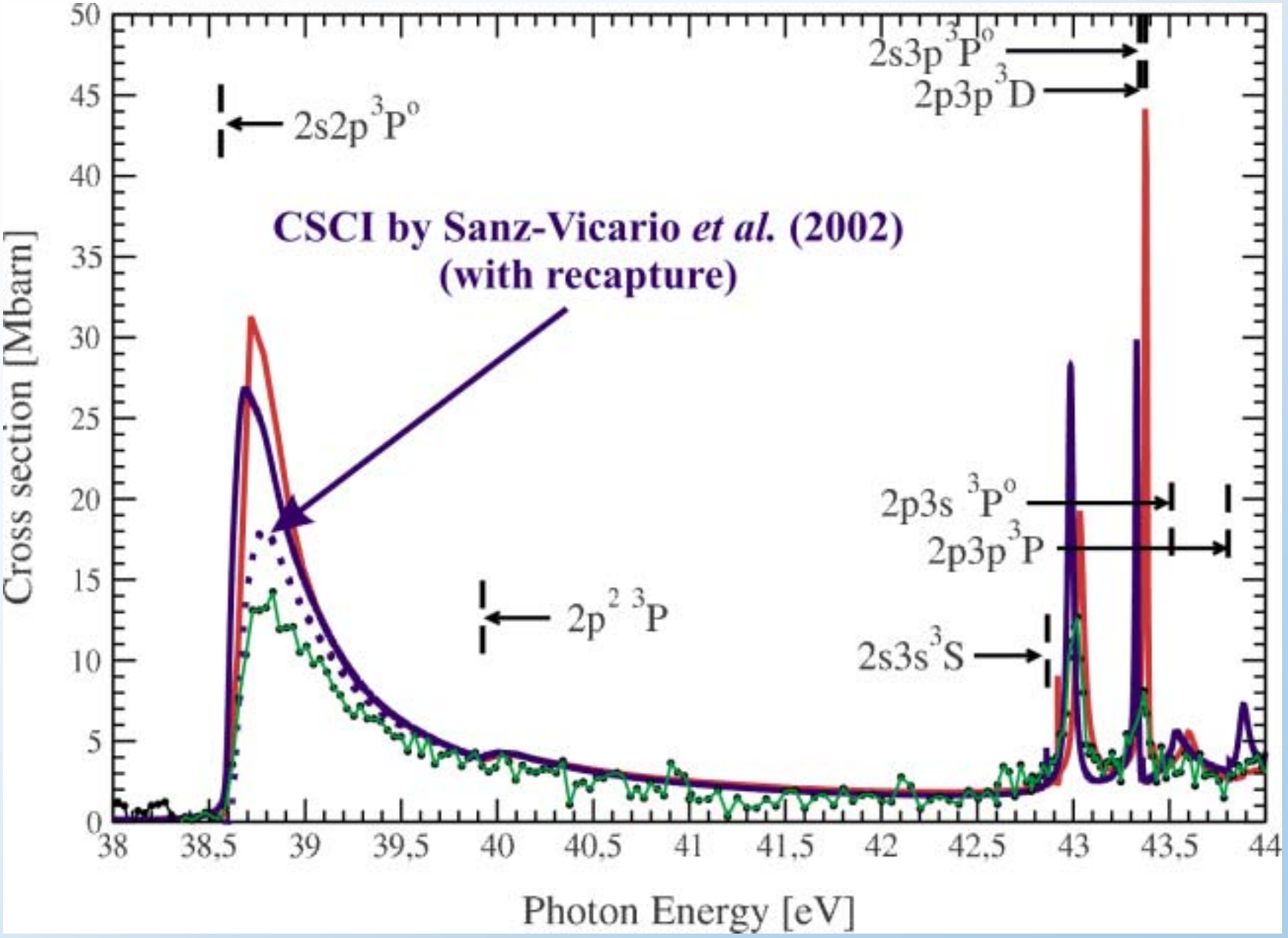
# Comparison between Experiment and Theories

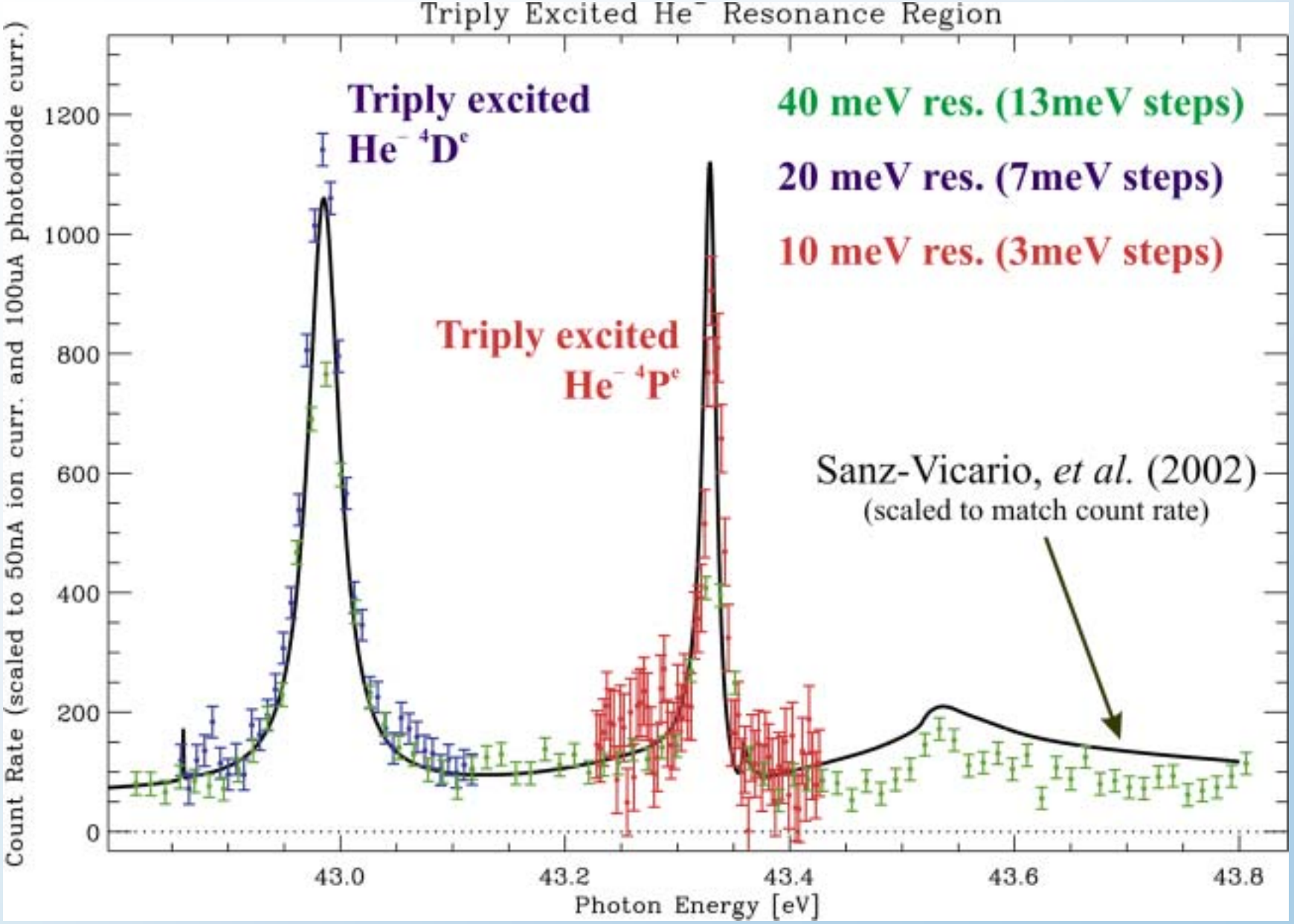


# Comparison with Positive ions

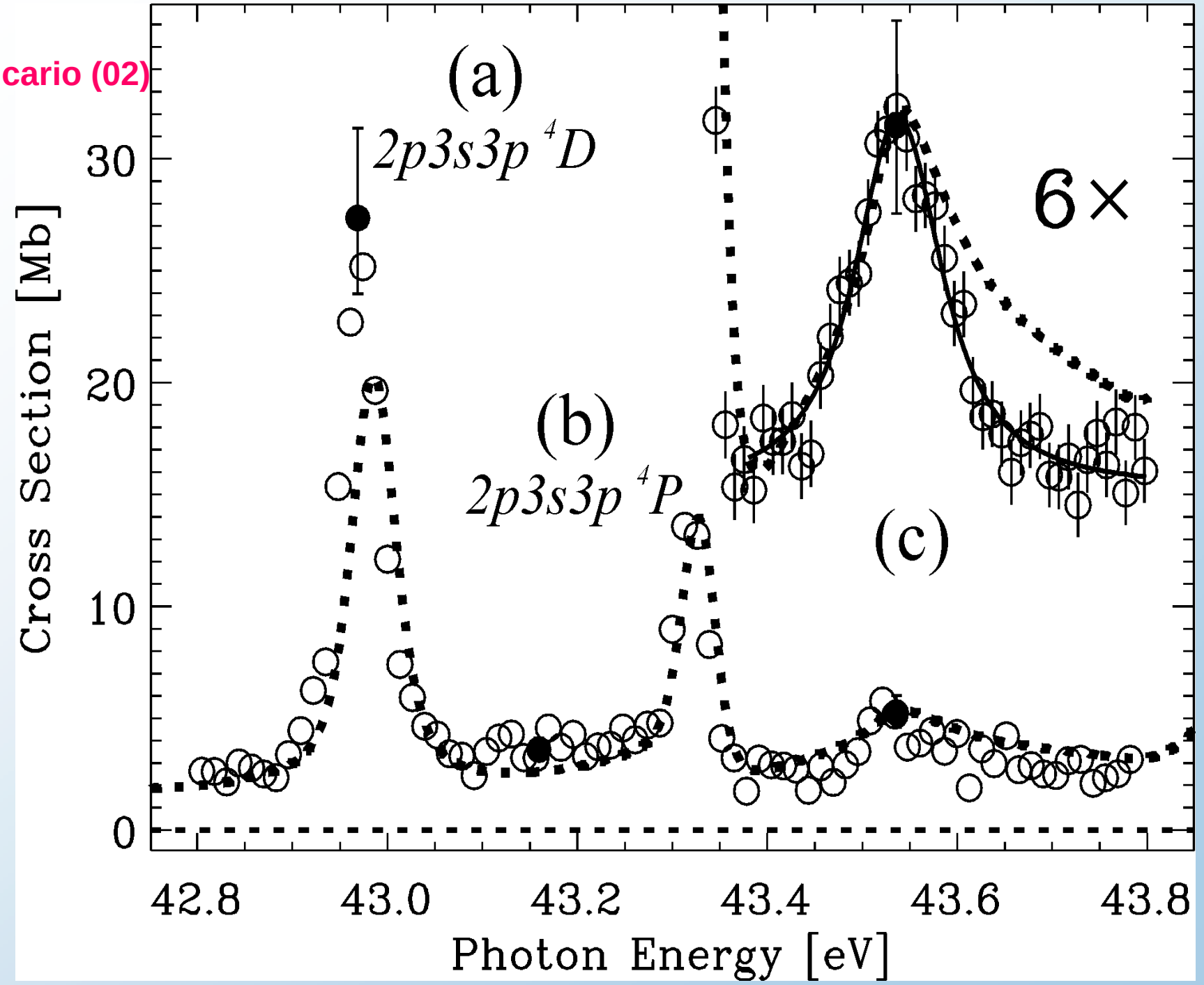
He+ is a one electron system and its cross section can be calculated analytically…




Cross section [Mbarn]
Photon Energy [eV]
0
5
10
15
20
25
30
35
40
45
50
38
38,5
39
39,5
40
40,5
41
41,5
42
42,5
43
43,5
44
2s2p 3P°
2s3p 3P°
2p3p 3D
CSCI by Sanz-Vicario et al. (2002)
(with recapture)
2p2 3P
2p3s 3P°
2p3p 3P
2s3s 3S


Triply Excited He⁻ Resonance Region
Triply excited
He⁻ ⁴Dᵉ
Triply excited
He⁻ ⁴Pᵉ
40 meV res. (13meV steps)
20 meV res. (7meV steps)
10 meV res. (3meV steps)
Sanz-Vicario, et al. (2002)
(scaled to match count rate)
Count Rate (scaled to 50nA ion curr. and 100uA photodiode curr.)
Photon Energy [eV]
0
200
400
600
800
1000
1200
43.0
43.2
43.4
43.6
43.8

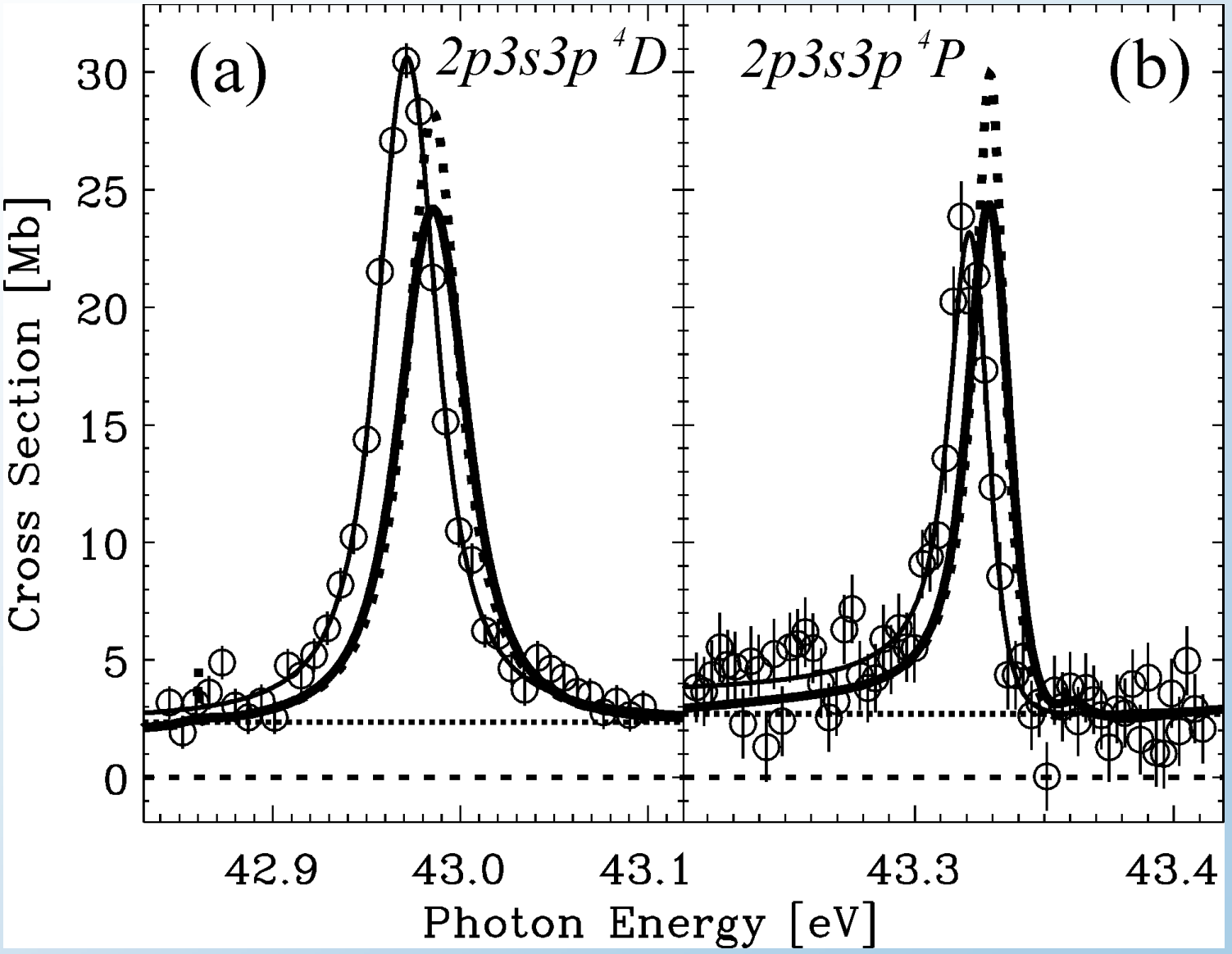
--- S. **Vicario (02)**


(a)
2p3s3p ⁴D
(b)
2p3s3p ⁴P
(c)
6×
Cross Section [Mb]
0
10
20
30
42.8
43.0
43.2
43.4
43.6
43.8
Photon Energy [eV]

--- S. Vicario

— Vicario Convoluted

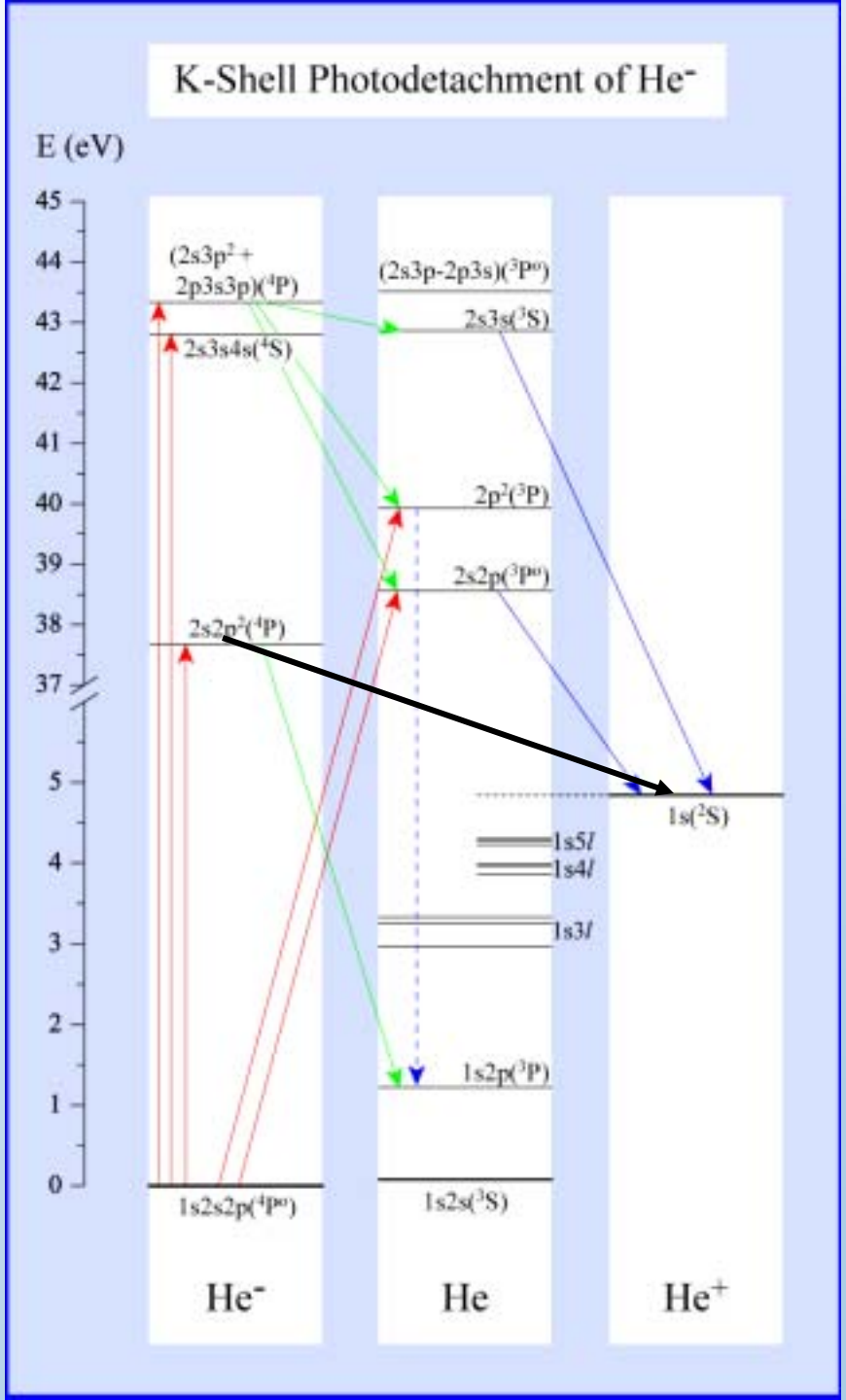
— Fit



# Observation of the $2s2p^2\ ^4P$ State of $He^-$

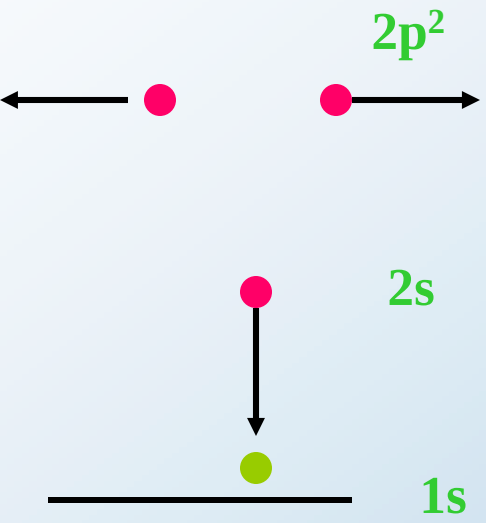
$h\nu + He^-(2s2p^2\ ^4P) \rightarrow He^+(1s\ ^2S) + e^- + e^-$

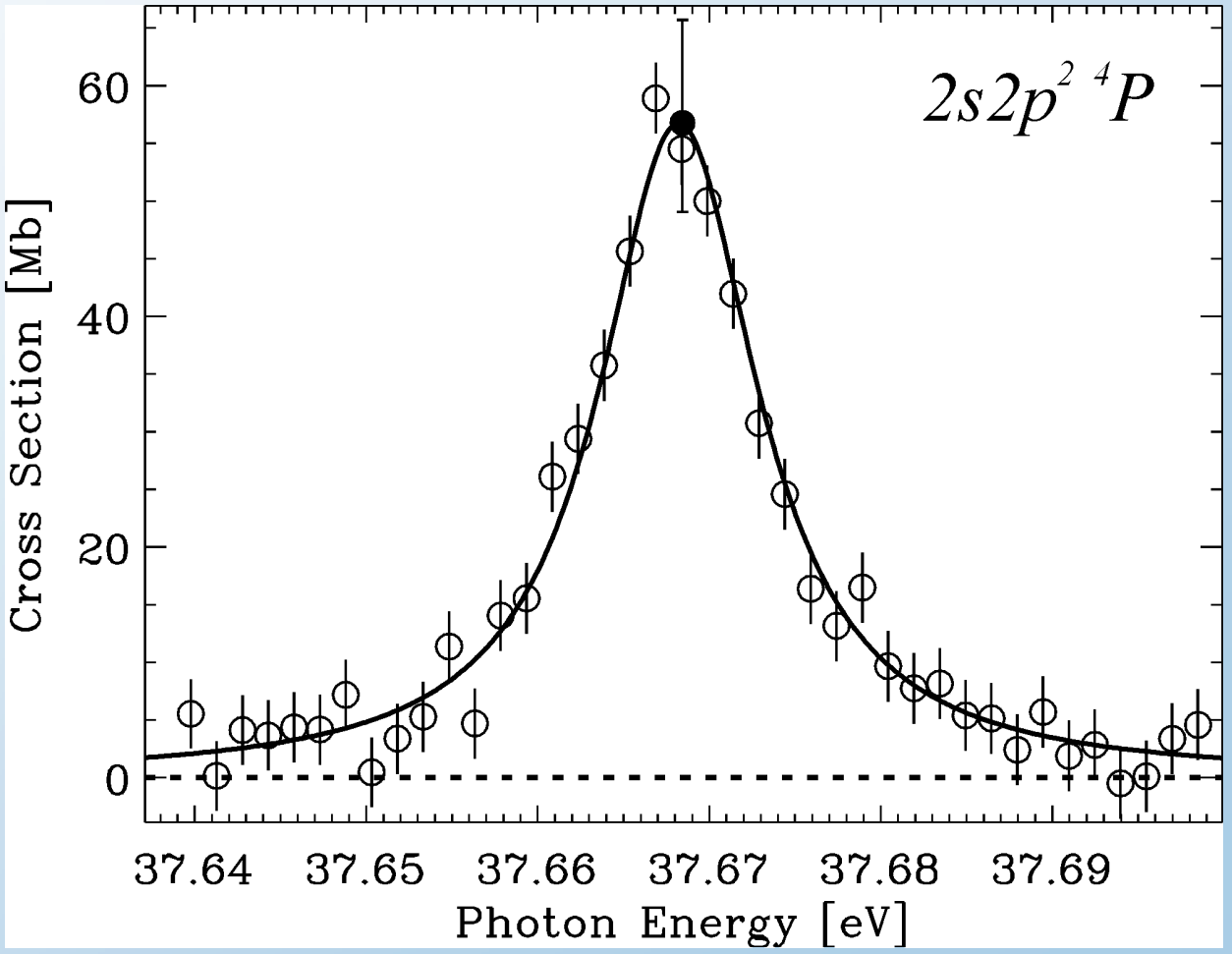
*Simultaneous $3e^-$ Decay Process!!!*



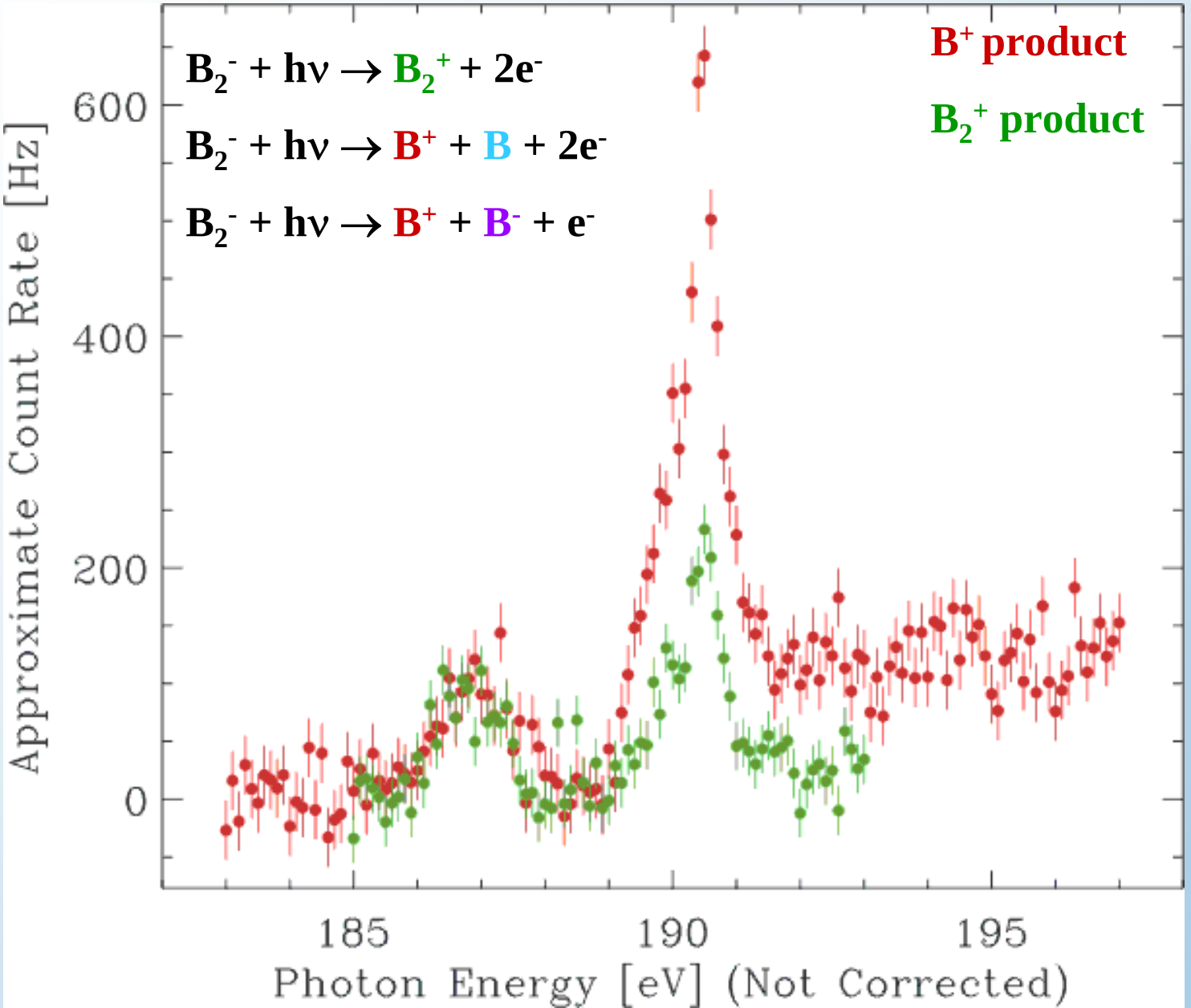
# Observation of the $2s2p^2\ ^4P$ State of $He^-$

**First Evidence of Simultaneous 3 $e^-$ Decay process in Core-Excited Negative Ions**

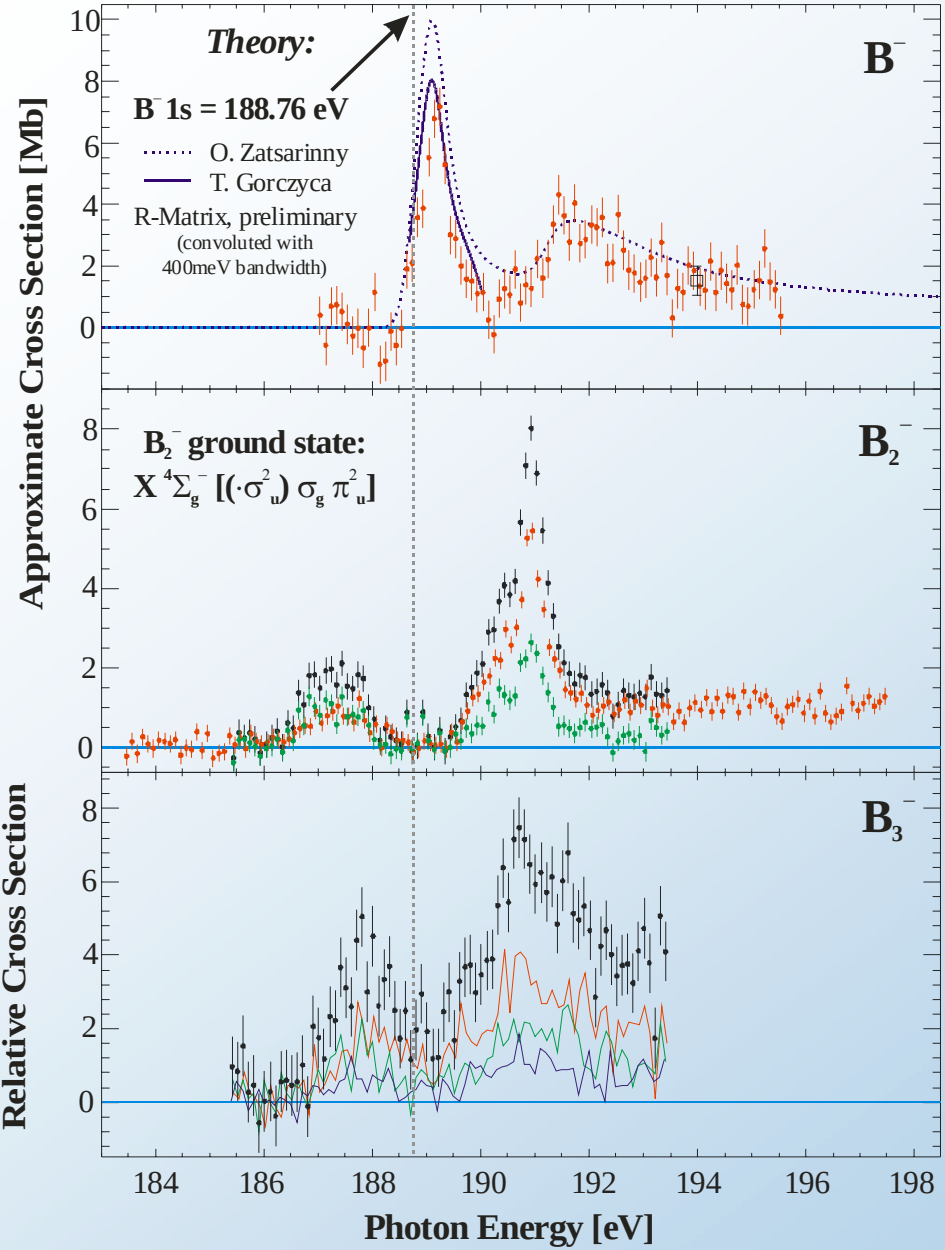


# Competition:Photodetachment and Photodissociation in $B_2^-$



# Photoionization of $B_n^-$




- Competition between Photodetachment & Photodissociation in $B_2^-$ and $B_3^-$

**Sum of meas. channels**

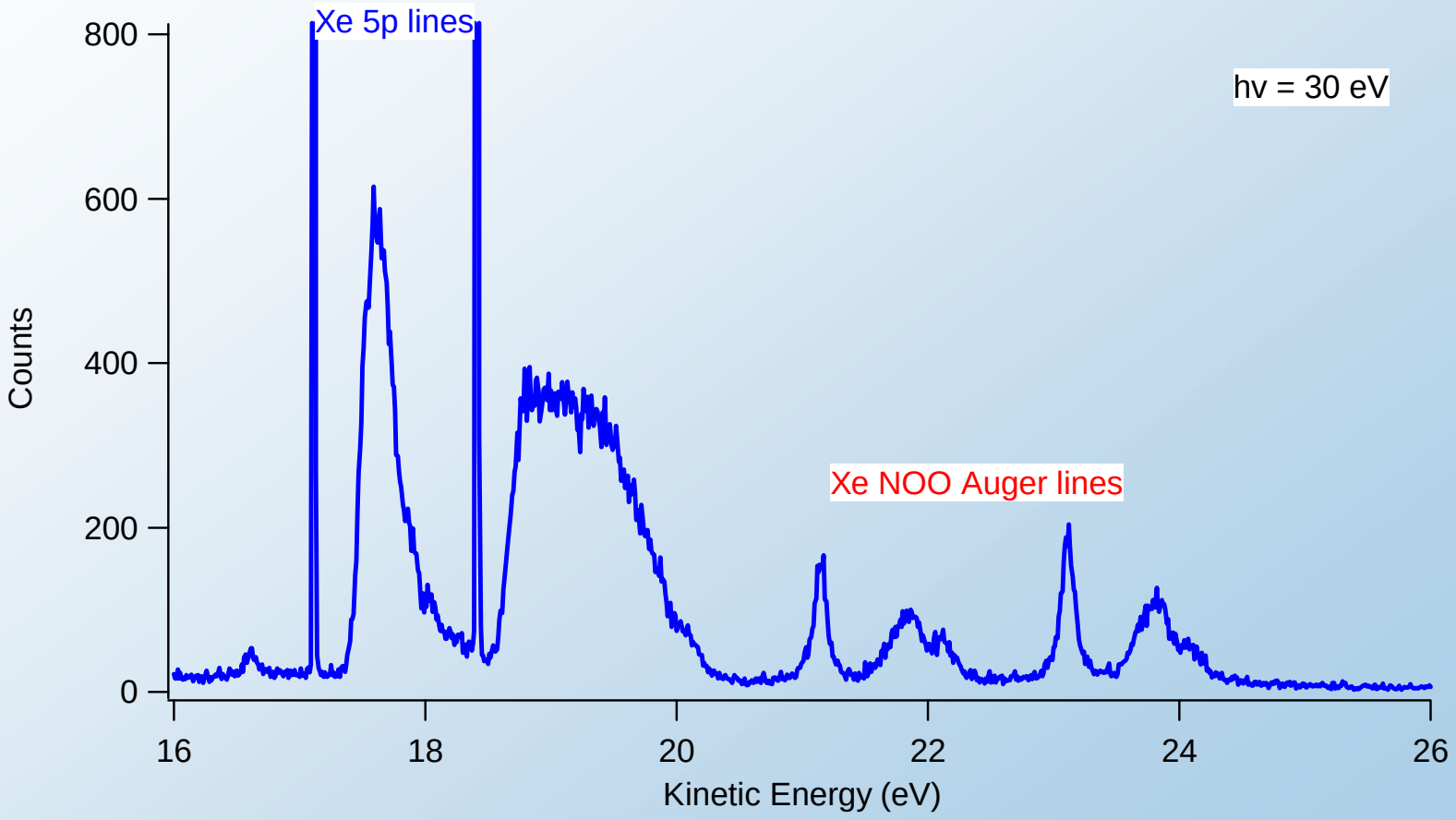
$B^+$ product

$B_2^+$ product

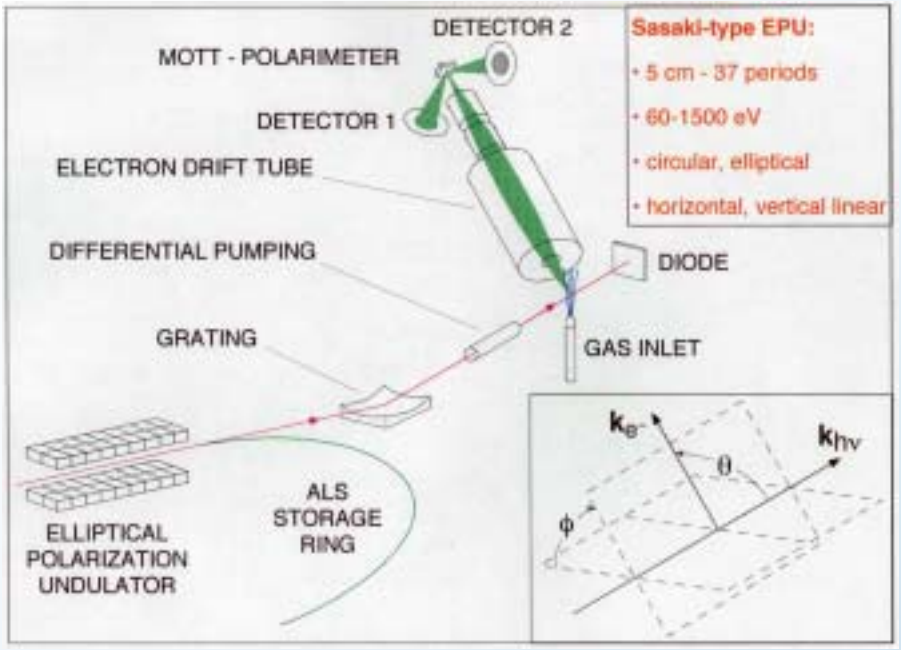
$B_3^+$ product

# van der Waals Clusters

Cluster peaks are much broader than narrow valence peaks…



# Spin polarized PES



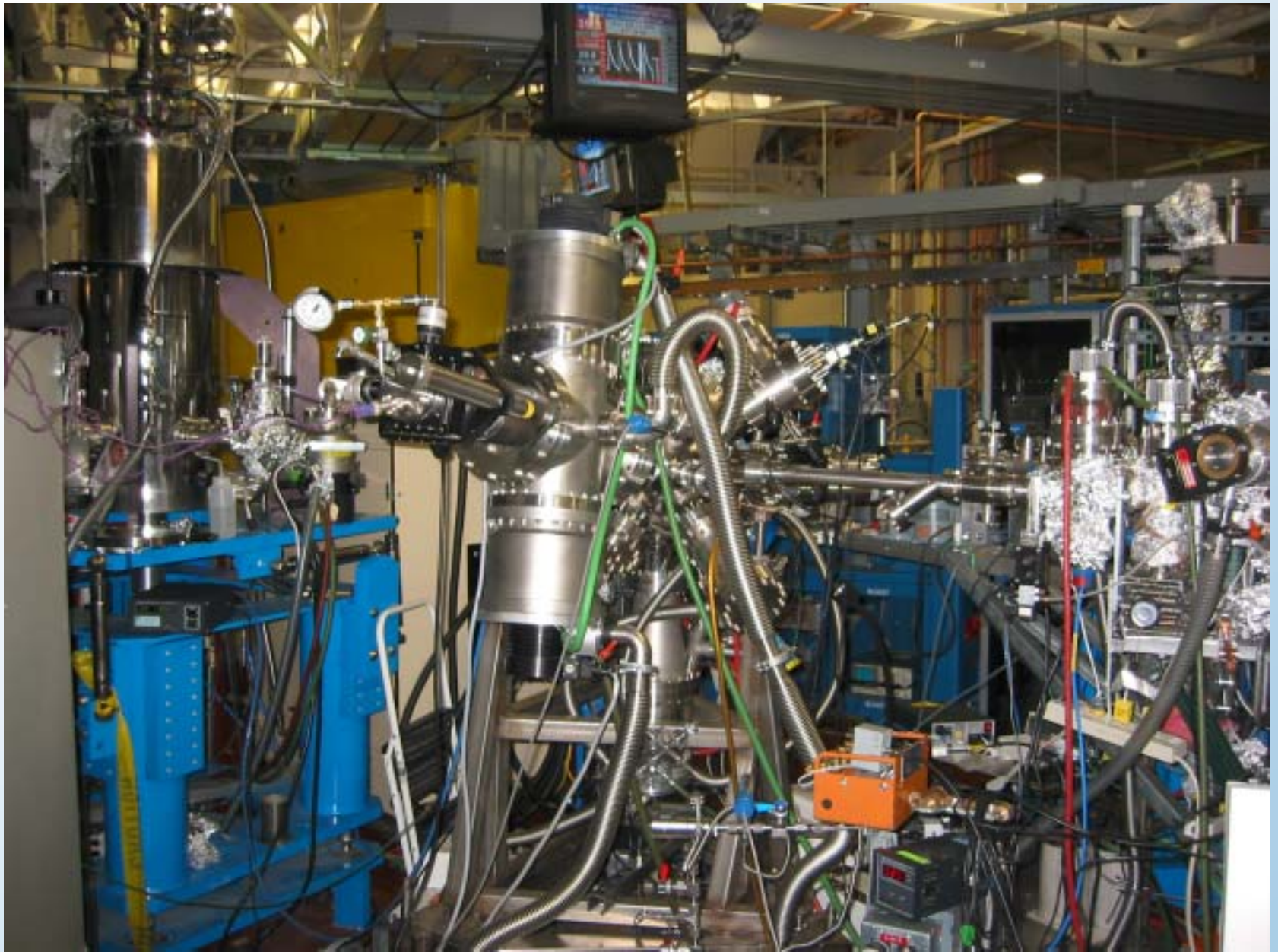


**Chiral molecules bromocamphor, C10H15BrO, N. Bowering, T. Lischke, B. Schmidtke, N. Muller, T. Khalil and U. Heinzmann, Phys. Rev. Lett. 86, 1187 (2001)**

**Atoms; G. Snell, B. Langer, A. T. Young and N. Berrah, ”Spin polarization measurements of the Kr M4,5NN and Xe N4,5 Auger electrons:orientation and intrinsic parameters”, Phys. Rev. A 66, 022701 (2002).**

**Molecules; G. Turrri, G. Snell, B. Langer, M. Martins, E. Kukk, S. E. Canton, R. C. Bilodeau, N. Cherepkov, J. D. Bozek, and N. Berrah, “Probing the Molecular Environment using Spin-Resolved Photoelectron Spectroscopy” Phys. Rev. Lett. 92, 013001 (2004).**

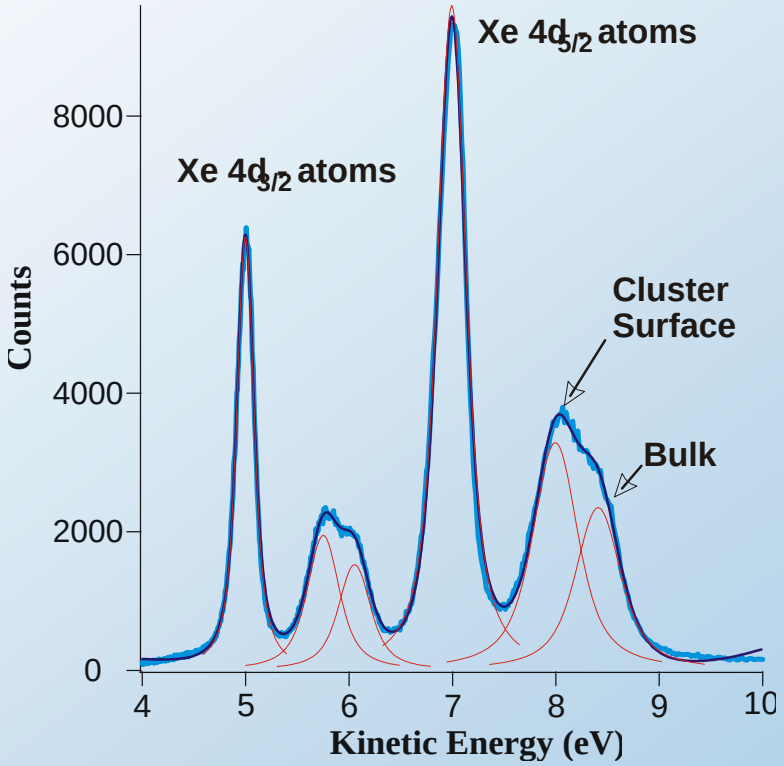
# Cluster source coupled to electron spin chamber



# Electron Spin Polarization, *P*

$$P = \frac{1}{S_{eff}} \frac{\sqrt{I_1^+ I_2^-} - \sqrt{I_1^- I_2^+}}{\sqrt{I_1^+ I_2^-} + \sqrt{I_1^- I_2^+}}$$

$$S_{eff} = -\ 0.13$$




| Xe $4d_{3/2}$ | | | Xe $4d_{5/2}$ | | |
|---|---|---|---|---|---|
| *atom* | *surface* | *bulk* | *atom* | *surface* | *bulk* |
| 0.50 | 0.51 | 0.41 | -0.37 | -0.38 | -0.26 |

- *Bulk exhibits decreased polarization vs atom or surface !*

# Many Thanks to

## Experimental Team

R.C. Bilodeau (WMU, ALS)
J. D. Bozek (ALS)
G. Turri (WMU,ALS)
A. Wills (WMU)
I. Dimitriu (WMU)
H. Zhang (WMU)
G. Heredia (WMU)
G. Ackerman (ALS)

## Theoretical Team

H.-L. Zhou (GSU)
S. Manson (GSU)
L. VoKy, France
A. Hibbert, Ireland
J. L. Vicario, Brazil
E. Lindroth, Sweden

# Supersonic Gas Jet

**J.D. Bozek, B.S. Rude, M. Wiedenhoeft, A.L.D. Kilcoyne, N. Berrah, G. Snell, R. Bilodeau, E. Kukk, G. Ackerman**

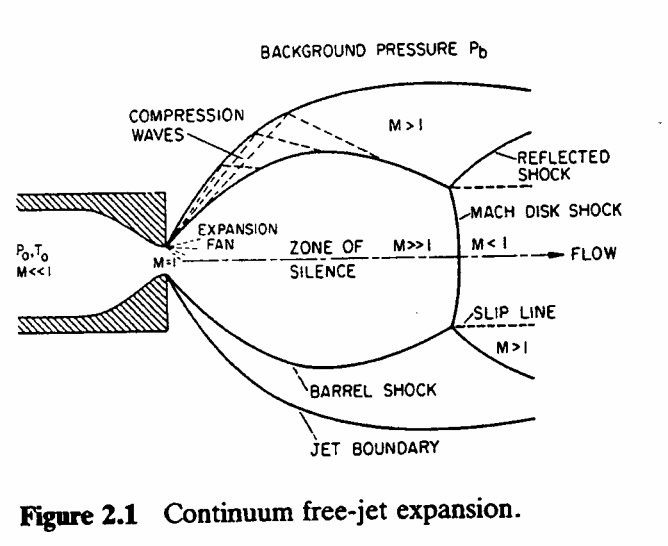
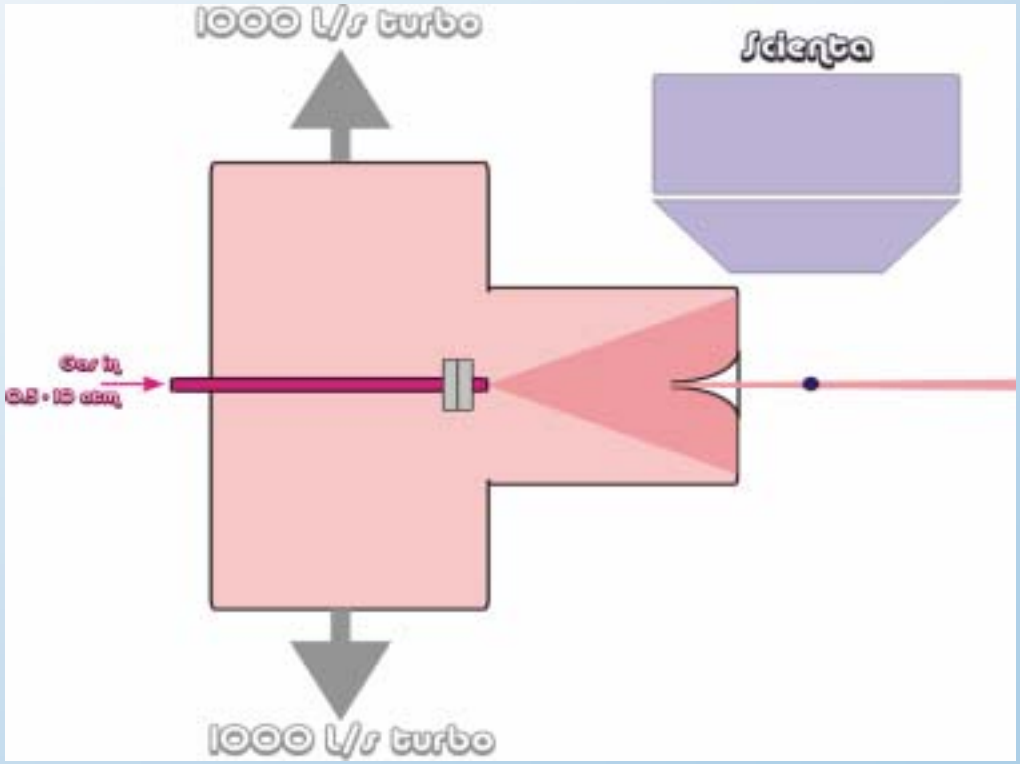



**Figure 2.1** Continuum free-jet expansion.

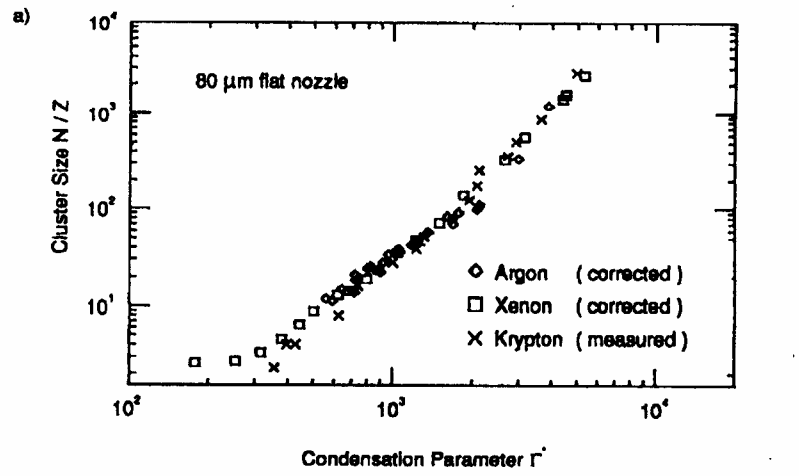


# van der Waals Clusters formed under right conditions

- Three-body collisions in the beginning stages of the expansion will result in condensation of gas into clusters
- Each gas has specific pressure & temperature requirements to produce clusters of a given size – several empirical models

$$\Gamma^* = k(p_0/\text{mbar})(d/\mu\text{m})^{0.85}/(T_0/\text{K})^{2.2875}.$$

| | He | Ne | Ar | Kr | Xe |
|---|---|---|---|---|---|
| k | 3.85 | 185 | 1646 | 2980 | 5554 |



# Xe Clusters

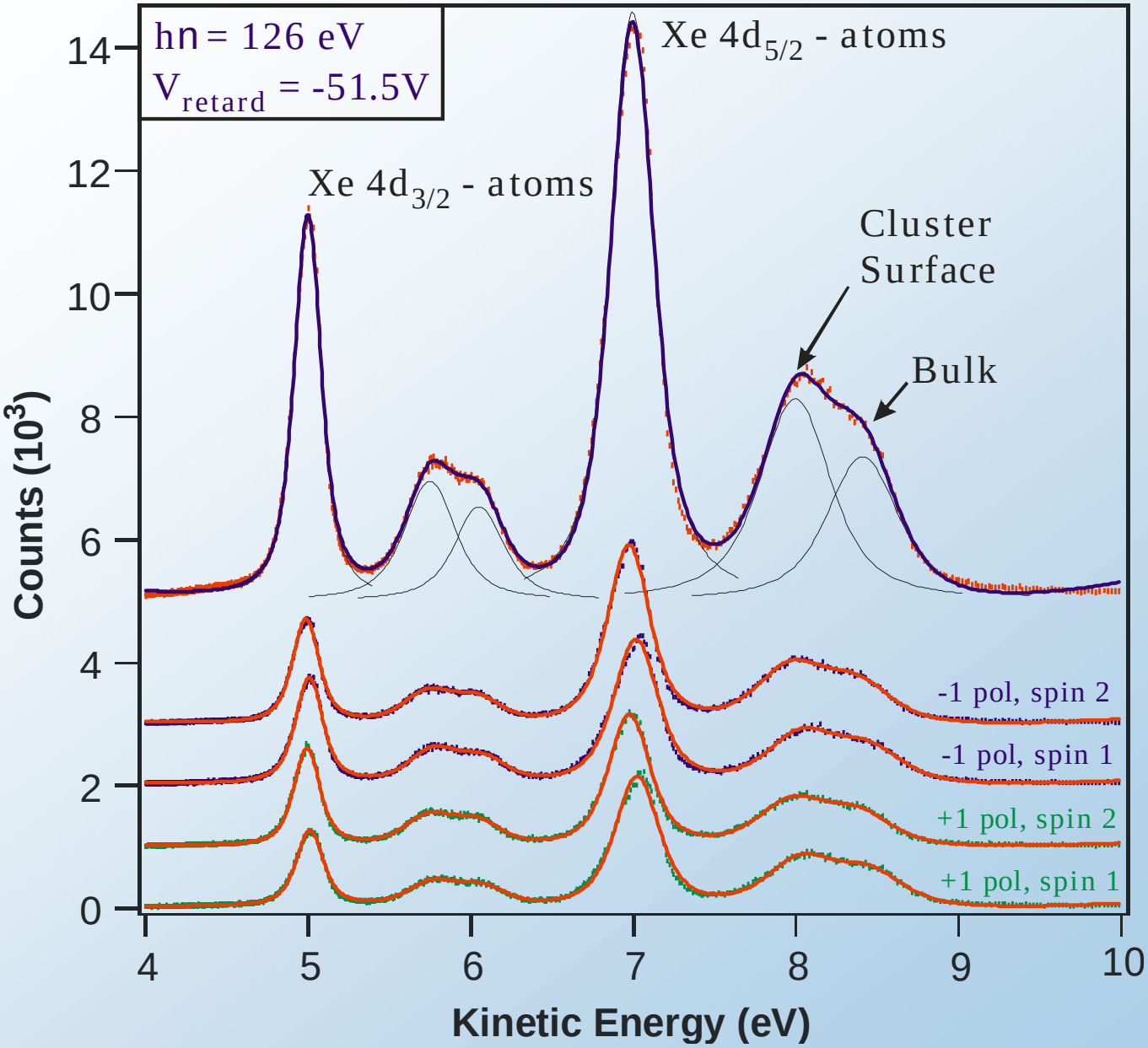

hn = 126 eV
V retard = -51.5V
Xe 4d5/2 - atoms
Xe 4d3/2 - atoms
Cluster
Surface
Bulk
-1 pol, spin 2
-1 pol, spin 1
+1 pol, spin 2
+1 pol, spin 1
Counts (10^3)
Kinetic Energy (eV)
0
2
4
6
8
10
12
14
4
5
6
7
8
9
10

TABLE I. Measured positions and widths of triply excited states compared with recent calculations. $\Delta$ is the difference between calculated and measured linecenters.

| Feature | Position [eV] | | | Width [meV] | | Ref. |
|---|---|---|---|---|---|---|
| | Meas. | Theory | $\Delta$ | Meas. | Theory | |
| $2s2p^2\ ^4P$ | 37.668(7) | 37.685 | 0.017 | 9.7(20) | 10.8 | [15] |
| | | 37.669 | 0.001 | | 9.66 | [14] |
| | | 37.703 | 0.035 | | 9.74 | [13] |
| | | 37.669 | 0.001 | | 9.85 | [12] |
| $2p3s3p\ ^4D$ | 42.972(4) | 42.980 | 0.008 | 29(5) | 35.0 | [15] |
| | | 42.985 | 0.013 | | 34.3 | [14] |
| $2p3s3p\ ^4P$ | 43.322(4) | 43.332 | 0.010 | 12(3) | 14.0 | [15] |
| | | 43.330 | 0.008 | | 13.8 | [14] |
| | | 43.370 | 0.048 | | 14.4 | [13] |